Universe Roadmap Chapter 3

Something from Nothing: The Origin and Evolution of Cosmic Structure

Why is there something rather than nothing? This is one of the oldest and deepest questions in philosophy, or indeed in human thought. The Beyond Einstein program seeks to address one aspect of this question: why does the Universe exist at all? But we must also ask why the Universe is not a formless continuum of matter --- a different kind of nothing --- but is filled instead with rich structure that extends from the cosmic horizon down to galaxies, stars, and planets.

Scope of Chapter

Given initial conditions and cosmic matter and energy contents (purview of Chapter 2), understand origin of cosmological structure, especially galaxies. Key questions:

- How did the first stars, galaxies, and quasars form, and how did they influence their surroundings?
- How do baryons and dark matter interact to form galaxies and systems of galaxies?
- How do supermassive black holes form and grow, and what are the interactions between SMBHs and their galactic hosts?
- How does the distribution of intergalactic baryons change with time?
- What is the formation history of our own galaxy, the Milky Way, and its immediate neighbors?

Some key points

- Eliminating SEU/Origins distinction allows much more rational science case, with Beyond Einstein missions making major contributions to understanding of cosmic structure.
- Most important missions:
  - JWST: Broadly applicable throughout, especially first objects, evolution of galaxies and quasars.
  - Con-X: Intergalactic medium, black hole population.
  - SIM: Milky Way structure, nature of dark matter.
- Significant contributions from Einstein Probes, LISA.
- Question marks: HST servicing? Origins Probes?
- Far future: SAFIR. Generation-X? Large UV telescope?

The First Stars, Galaxies, and Quasars

• Key issues: History of first stars, galaxies and quasars. Sources and timing of cosmic reionization. Feedback from first objects.

• Methods:

- • Direct detection with JWST.
- • Spectroscopy of quasars, GRB afterglows with JWST.
- • Reionization history from Inflation Probe.
- • Investigation of enrichment “fossil record” in oldest Milky Way stars, intergalactic medium, with UV-sensitive spectroscopic capability.
- • Long-term: detection of faint objects with SAFIR. Molecular spectroscopy to diagnose cooling mechanisms.

Formation and Evolution of Galaxies

- Key issues: Cosmic history of star formation, galaxy assembly, interplay of baryons and dark matter, feedback.
- Methods:
    - Panchromatic surveys, the more depth, area, and wavelength coverage the better. HST, Spitzer, GALEX, WISE, JWST, Dark Energy Probe, SAFIR, …
    - Resolved galaxy images with JWST. Spectra for dynamics, chemical enrichment.
    - Weak lensing measurements of dark matter with JWST, DEP.
    - UV and X-ray spectroscopic studies of galactic outflows.

The Galaxy-Black Hole Connection

- Key issues: Origin of bulge-BH correlation. Role of AGN in galaxy formation. Growth of black hole population by accretion and mergers. Black hole census. Importance of obscuration.

- Methods:

    - Panchromatic surveys, X-ray to far-IR, to get energy budget, obscuration. Go faint to detect first objects.

    - JWST measurements of dormant black holes in local galaxies.

    - JWST measurements of quasar hosts.

    - Con-X measurements of masses, accretion rates, spins.

    - Comprehensive census of bright AGN from BH finder.

    - Merger rates from LISA.

The Intergalactic Medium

- Key issues: Location and physical state of "missing baryons." Physical processes in intracluster gas, role of AGN heating. Extension to halos of individual galaxies. IGM enrichment.

- Methods:

    - X-ray absorption lines with Con-X.

    - UV absorption lines with ??? UV emission line mapping?

    - Con-X measurements of galaxy clusters. Additional info from SZ and weak lensing (Inflation and DE Probes).

    - Con-X measurements of galaxy X-ray halos.

The Milky Way and Its Neighbors

- Key issues: Structure and origin of main components of Milky Way – dark halo, thin disk, thick disk, bulge, stellar halo. Nature of dark matter. Constraints on “dim” compact objects.

- Methods:

  - SIM proper motions: mass of thin disk, presence of tidal streams in stellar halo, origin of thick disk, fate of dwarf satellites. Radial profile, shape, and substructure of dark matter halo.

  - SIM distances: stellar ages, hence chemical and dynamical history.

  - SIM microlensing studies: census of dim objects, nature of microlensing events towards LMC.

  - JWST microlensing of M87.

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Concluding Remarks

• New Universe missions can reach to epoch of first stars, galaxies, and quasars.

• Observing first objects and understanding galaxy evolution requires high sensitivity in near- and mid/far-IR, high angular resolution. Wide field panchromatic surveys, weak lensing, also valuable.

• Black holes appear to play important role in galaxy evolution. Understanding black hole evolution requires panchromatic studies, with X-ray observations especially important.

• Probing the “missing baryon” reservoir requires X-ray sensitivity, UV sensitivity.

• SIM can transform understanding of Milky Way, test origin of its stellar components, nature of dark matter.